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Miscellaneous Paper MP73

Toward the Inventory of Ontario's Mineral Aggregates

By

W.R.Cowan

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ABSTRACT

The availability of mineral aggregates for construction purposes is rapidly declining through inadequate resource planning, restrictive zoning and legislation, and competing land uses. The Geological Branch of the Ontario Ministry of Natural Resources has undertaken to provide aggregate inventory reports for all townships designated under The Pits and Quarries Control Act, 1971, and eventually for all townships in heavily populated areas. The reports contain maps and recommendations for extractive zoning by municipalities; of necessity only the largest deposits are given priority recommendations. It is intended that these reports should improve the resource planning in areas underlain by large aggregate deposits. The inventory is only possible because a concentrated effort has been made to map the Quaternary geology of populated areas over the last ten years. Future needs require that we develop methods to determine the extent of poorly defined and buried aggregates and that we look for natural alternatives.

TOWARD THE INVENTORY OF ONTARIO'S MINERAL AGGREGATES [1]

by

W.R. Cowan[2]

INTRODUCTION

The management of non-renewable resources in areas of high land-use stress requires acceptance of the concept of sequential land use planning. To accomplish such planning, and to avoid sterilization of mineral resources, adequate inventories of naturally occurring mineral resources are necessary, particularly mineral aggregates which are a high volume–low unit price commodity. In Ontario the inventory of mineral aggregates is the task of the Phanerozoic Geology Section, Geological Branch of the Ontario Ministry of Natural Resources, which is responsible for the geological survey of Ontario's post Precambrian soil and rock materials. With the help of many agencies and individuals we are now in a position to provide aggregate inventories to most municipalities within the more densely populated areas of Ontario. In this regard we feel we are the leader amongst North American state and provincial geological surveys.

This paper outlines the development and methodology of our inventory and is directed at the primary users i.e. planners, municipal officials, and consulting engineers. The inventory of Ontario's mineral aggregates may be divided into three phases, The Early Years, The Present Inventory, and The Future.

THE EARLY YEARS (1948-1968)

Modern day inventory of Ontario's mineral aggregates may be considered to have begun in 1948 when the late Donald F. Hewitt was appointed Industrial Minerals Geologist for the Province of Ontario. Following several years reporting on the numerous industrial minerals which occur within the Grenville Structural Province, Hewitt directed his attention to the study of commercial limestone deposits which resulted in a detailed report in 1960. At about that time, (1957-1964) P.F. Karrow mapped Pleistocene geology for the Ontario Department of Mines within areas identified as containing possibly large gravel resources. These two men combined efforts to produce "Sand and Gravel in Southern Ontario" (Hewitt and Karrow 1963) which relied heavily on the reconnaissance scale physiographic mapping of L.J. Chapman and D.F. Putnam (1951). Simultaneously, Hewitt was drawing attention to the rapid urban expansion in Ontario, the need for sequential land use planning, the need for rehabilitation of pits and quarries, and the urgent need to inventory and properly manage our finite resources of mineral aggregates as well as other industrial minerals (Hewitt 1962; 1968; Hewitt and Vos 1970; Hewitt and Yundt 1971). The Niagara Escarpment Protection Act, 1970 and its successor, The Pits and Quarries Control Act, 1971 in part resulted from Hewitt's tireless efforts. These served to focus attention on the mineral aggregate

[1]A paper presented at the 79th Annual General Meeting of the Canadian Institute of Mining and Metallurgy, Ottawa, 20 April, 1977. The original version of this paper was published as Appendix 3 in "A Policy for Mineral Aggregate Resource Management in Ontario", the report of the Ontario Mineral Aggregate Working Party to The Honourable Leo Bernier, Minister of Natural Resources (published by the Ministry of Natural Resources, January 1977).

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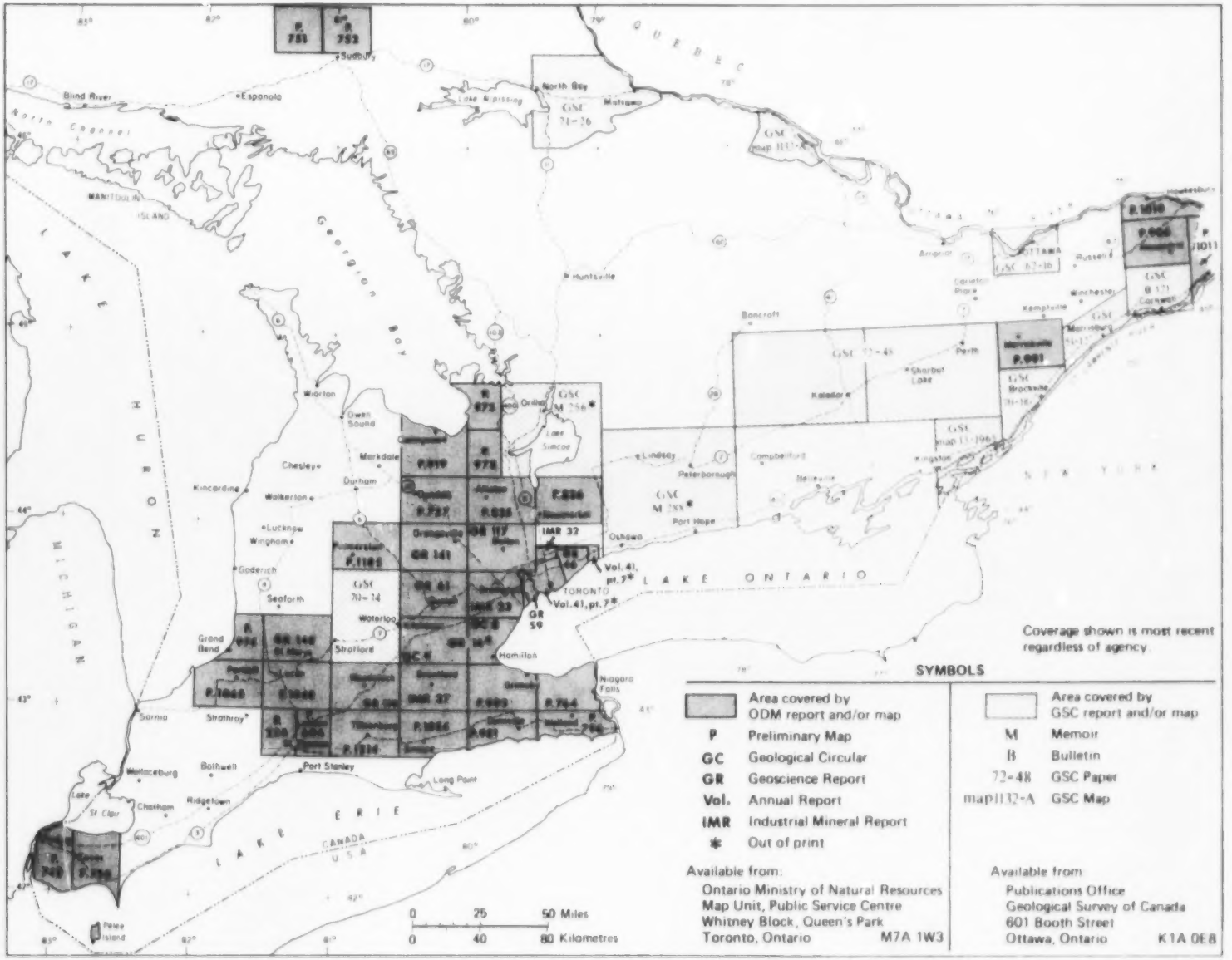

Figure 1–Index to published maps and reports of Quaternary geology in southern Ontario

industry and brought the need for aggregate inventory and planning to a state of urgency.

THE PRESENT INVENTORY (1968-1980)

To carry out aggregate inventories the first need is maps of bedrock formations, which may be used as crushed rock sources, and maps of the unconsolidated surficial soil materials (variously referred to as maps of glacial geology, surficial geology, Pleistocene geology, and Quaternary geology) for locating surface or near surface deposits of sand and gravel. By 1968 bedrock maps were available for most of southern Ontario, however only a few thousand square miles of surficial geology had been mapped by the Ontario Department of Mines and the Geological Survey of Canada (GSC). Consequently mapping of Quaternary geology was re-activated by the Ontario Department of Mines in 1968 with the hiring of one Quaternary geologist. The staff was continuously increased until by 1974 we had six Quaternary geologists, one Paleozoic geologist, and two resource geologists. In addition a limited amount of contract work has been carried out.

The result of this increased effort to map the surficial materials at a scale of 1:50,000 is shown in Figure 1; note that much of the area east of Toronto was mapped by the GSC without which we would be in a much less fortunate position to carry out inventories. In addition we have mapped the areas immediately surrounding the northern centres of Sudbury, Sault Ste. Marie, and Thunder Bay, while the Timmins-Kirkland Lake area was mapped by the GSC, though at a smaller scale. It is hoped that by 1980 we will have surficial geological maps available, from one source or another, for the southern part of the Province underlain by Paleozoic bedrock formations.

Bedrock Aggregates

Maps showing the location of bedrock aggregates within a municipality are relatively easy to obtain. Firstly the bedrock geology map is examined to determine whether any suitable formations are present within the area. This suitability depends on physical properties and the capability of the rock to withstand stresses placed upon it when it is used as a construction material. Surprisingly few areas are underlain by quality aggregate forming rocks, the best in southern Ontario being the rock which forms the cuesta of the Niagara Escarpment. Given a suitable rock unit, a map showing the thickness of overburden is consulted to determine the feasibility of quarrying the rock; generally 25 feet (8 m) of overburden is considered to be the maximum though up to 50 feet (15 m) or more is tolerated for special products. This information is combined to show the areal extent of feasible quarrying. This is then combined with a rock thickness estimate and specific gravity to give a gross tonnage estimate. Obvious cultural constraints may be subtracted to give a net tonnage. The data may then be submitted to a municipality for extractive zoning consideration.

Granular Aggregates

The assessment of granular aggregates is somewhat more complex than that of the bedrock because of the greater number of deposits (though of smaller size), greater variety of materials, and because available information is often of poorer quality. Much more interpretation is involved and the degree of error can be high though tonnage estimates would usually be conservative. Reports provided to municipalities contain two or three maps: a Quaternary geology map; a granular aggregates probability map; and an extractive area recommendation map. Usually only the first and one of the two latter maps would be provided depending on the nature of the available data.

QUATERNARY GEOLOGY MAPS

These maps show the distribution, nature, and stratigraphy of the various glacial deposits found within an area. Figure 2 is a simplified example of such a map. These usually show a variety of tills of different ages and compositions, sands, silts, clays, and gravels. Tills (Photo 1) are mixtures of mud and rock fragments deposited by a glacier. Sands were deposited by glacial meltwaters flowing as rivers (outwash sands) or deposited into glacial lakes (lacustrine sand), and silts and clays were deposited by and into glacial meltwaters. Gravels were deposited by glacial meltwaters (outwash gravels), as beach or deltaic gravels related to glacial lakes, or as eskers, kames, and morainic deposits collectively described as ice-contact stratified drift because they were deposited in contact with ice at or near glacial margins.

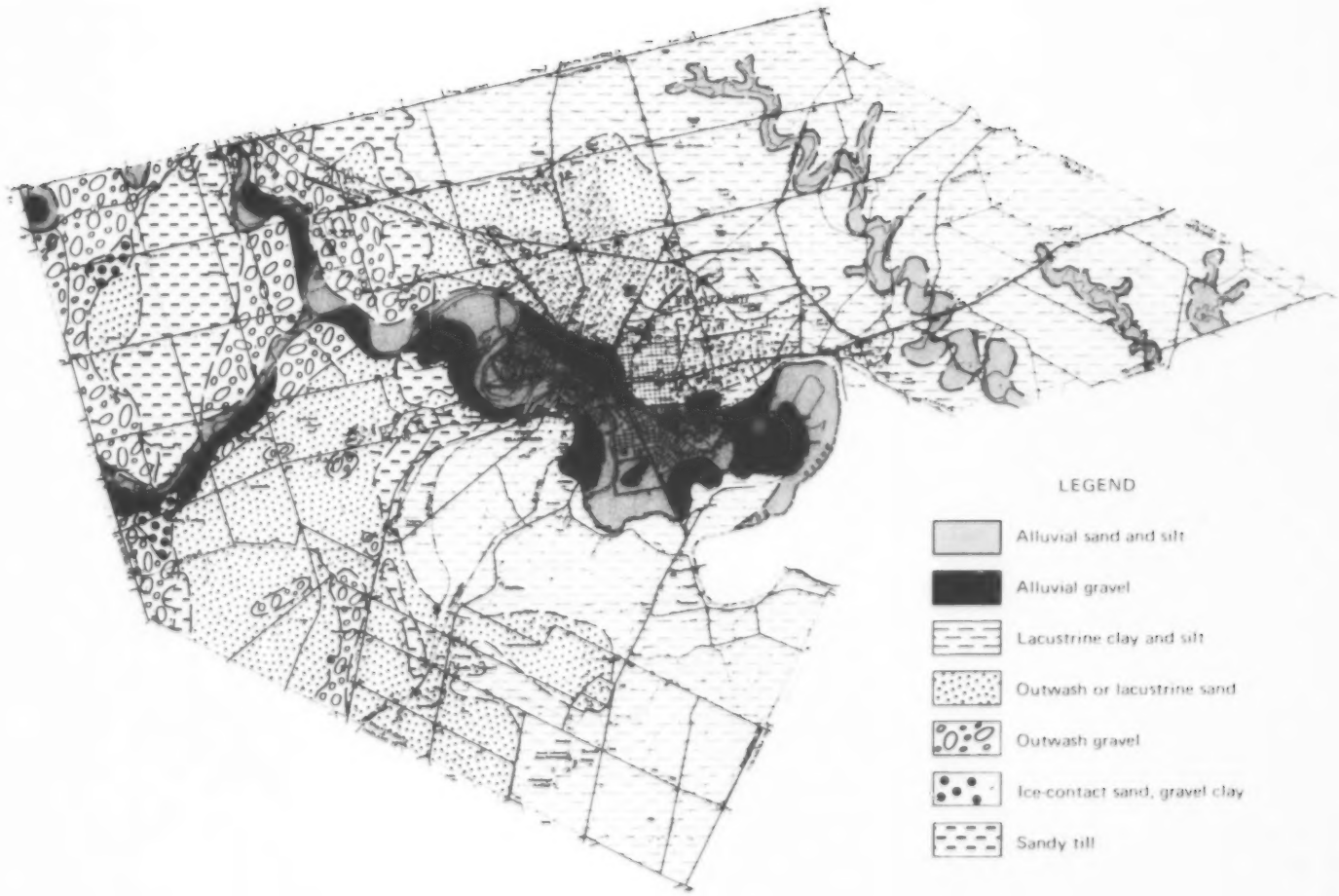

Figure 2–Brantford Township, generalized Pleistocene geology

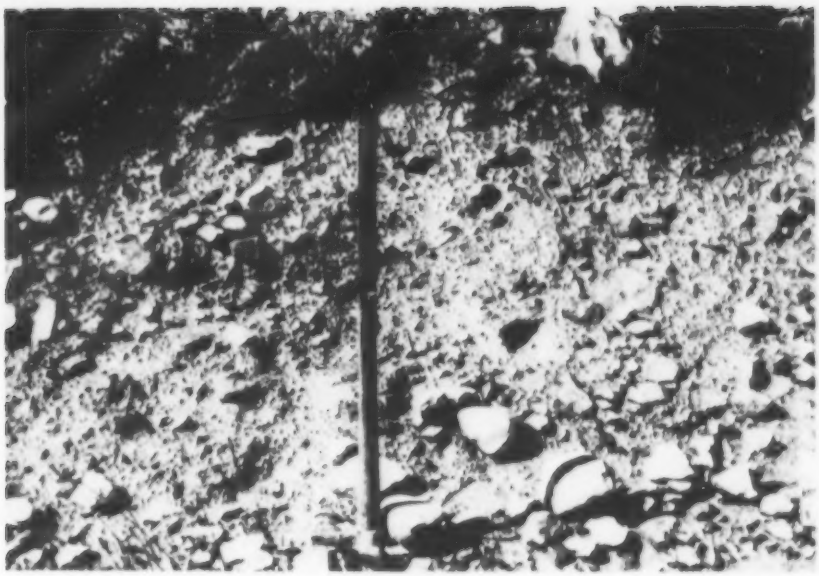

Photo 1—Till (sandy silt texture), Harriston Ontario.

Quaternary geology maps are constructed by combining field data, filed geotechnical data obtained from government or private engineering agencies, and air photo interpretation. Field work consists of traversing roads, and examining road cuts, gravel and sand pits, and excavations by test pitting and clearing of debris, and through augering with soil testing apparatus. Stream and lake bluffs are also examined, and where necessary additional information is gained from traversing private property. These data are used to determine the nature, thickness, and vertical and horizontal relationships of different geologic units which are frequently discontinuous and very thin. Field surveys at a scale of 1:50,000, carried out by one field crew, consisting of a geologist and three university students employed for the summer, cover 300 to 500 square miles (800 to 1300 km^2) per summer depending on the complexity of the geology.

These field data are augmented from water well records maintained by the Ministry of Environment, geotechnical data filed by the Ministry of Transportation and Communications, and data provided by municipal and consulting engineers and pit or quarry operators. Combining the known data with air photo interpretation results in a map which superficially is a two dimensional portrayal of the geology; however a trained geologist judiciously using the legend and any accompanying report can formulate a reasonable understanding of the three dimensional picture.

GRANULAR AGGREGATES PROBABILITY MAPS

The Quaternary geology map is a basic tool for use by geologists, soils engineers, and persons conversant in geology. However many users require derivative maps which sort mapped variables into a specific theme for direct application. For this reason we produce *granular aggregates probability maps* (Figure 2) which divide the mapped area into high, moderate, or low categories depending on the interpreted potential a specific zone has for aggregate production. Similar maps have been produced in Illinois (e.g. Hackett and McComas 1969) and in Colorado (Schwochow *et al.* 1974) though the latter are not described as probability maps.

The probability maps are direct interpretations of the geology and are best compiled by a geologist familiar with the area. The stratified, aggregate forming, glacial deposits of southern Ontario are summarized below and in Table 1 to demonstrate how a probability designation for a map unit might be interpreted from a Quaternary geology map.

Recently the map-areas have been divided into units indicating possible number of tons per acre (Table 2). This classification can be improved further by adding data on the coarseness and quality of the aggregate.

TABLE 1 | TYPES OF SAND AND GRAVEL DEPOSITS AND THEIR PROPERTIES.

PROPERTIES	GLACIOFLUVIAL			
	Outwash		Ice-contact	
	Sheet Deposits	Valley Train	Esker	Kame
Shape (Plan)	Tabular	Elongate	Elongate	Equi-dimensional
Topography	Flat (may be pitted)	Flat-terraced	Rolling-beaded ridge	Hummocky
Associated features		Meltwater channels	Commonly ∥ to glacial flow	Ice-contact slopes
Thickness (feet)	5-100	5-100	10-100	10-100+
Bedding	Largely horizontal variable development	Abundant X-bedding	Abundant X-bedding	Abundant X-bedding
X-bed orientation	Variable	Well oriented	Variable, may be well oriented	Very variable
Sorting	Poor to moderate	Poor to moderate	Poor to moderate	Poor to moderate
Rounding (pebbles)	Subangular to rounded	Subangular to rounded	Subangular to rounded	Angular to subrounded
Deformation (faulting and slumping)	Very local	Very local	Common	Common
Other features	Proximal - distal facies	—	Highly variable	Highly variable, till inclusions
Coarse aggregate probability	Moderate to high	High	Moderate	Moderate
Comments	Uniform to variable	Uniform	Variable	Very variable

	GLACIOLACUSTRINE		GLACIOMARINE	
Moraine	Beach	Delta	Beach	Delta
Broad Elongate	Elongate	Tabular	Elongate	Tabular
Hummocky ridge	Bar or Bluff	Flat top, delta front	Bar or Bluff	Flat top, delta front
⊥ to glacial flow	Existing lakes nearby	Existing lakes nearby	Occur around topographic highs	Related shorelines
10-100+	5-40	10-100	5-40	10-100
Abundant X-bedding	Well stratified, X-bedding common	Largely horizontal, may have foresets	Well stratified plane bedding, some X-bedding	Largely horizontal, may have foresets
Very variable	Bimodal to variable	May be well oriented	Bimodal to variable	May be well oriented
Poor to moderate	Poor to well	Poor to moderate	Poor to well	Poor to moderate
Angular to subrounded	Subangular to well rounded	Subangular to rounded	Subangular to well rounded	Subangular to rounded
Common	Nil	Very local	Nil	Very local
Highly variable till may be present	Pebbles may be imbricated	—	Pebbles may be imbricated, fossiliferous, clay bands	May be fossiliferous
Moderate to low	High on coarse substrate	Low	High on coarse substrate	Low
Very variable	Uniform, may be fine	Fine	Uniform, may be clayey in offshore bars	Fine

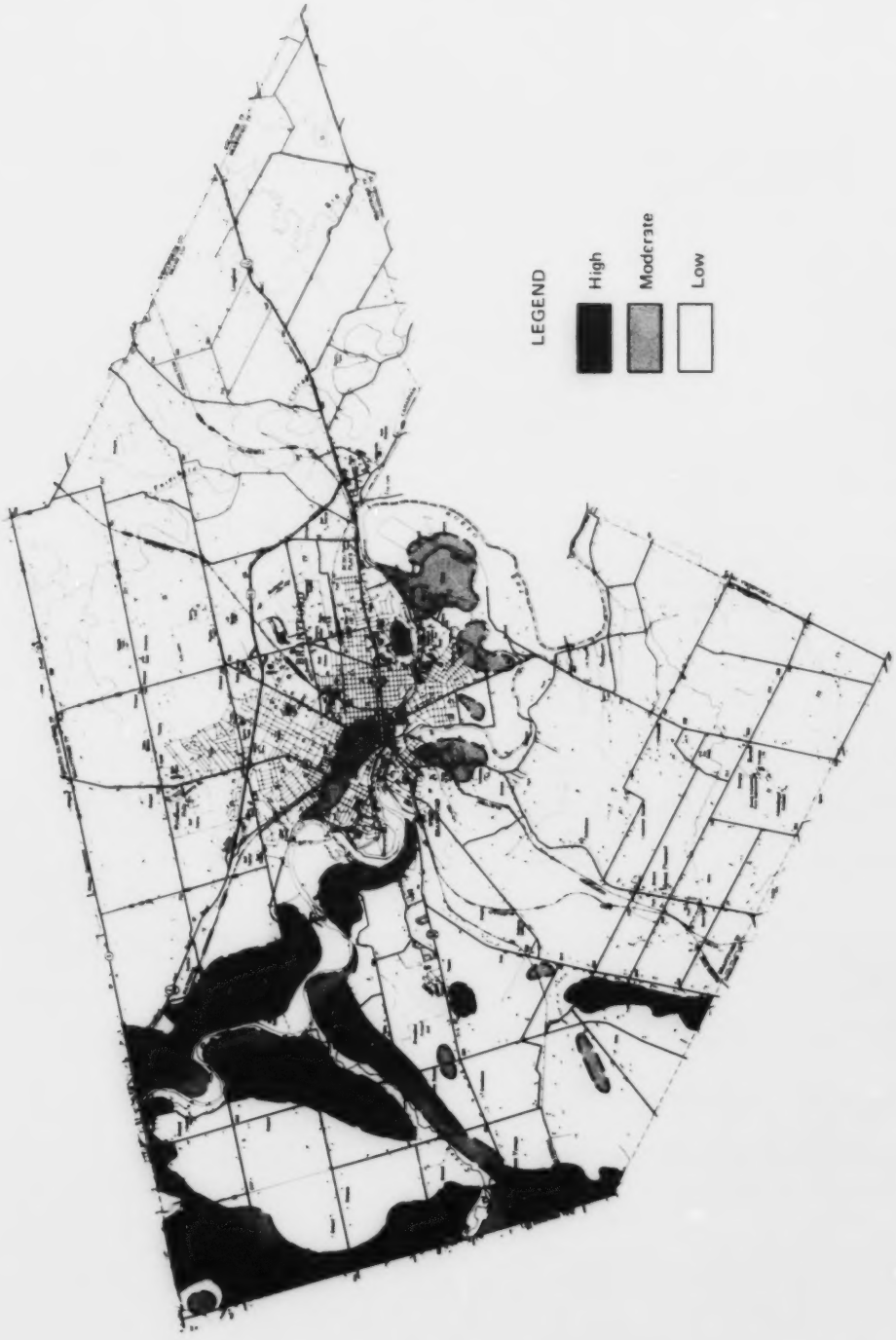

Figure 3–Brantford Township, showing areas of high, moderate and low probability of having coarse granular aggregate.

TABLE 2 | SIMPLE MAP CLASSIFICATION OF GRANULAR AGGREGATES.

Origin	Tons per acre (thousands)			
	> 50	25-50	12.5-25	< 12.5
Glaciofluvial				
Outwash	OW-1	OW-2	OW-3	OW-4
Ice-contact				
Esker	E-1	E-2	E-3	E-4
Kame	K-1	K-2	K-3	K-4
Kame Terrace	KT-1	KT-2	KT-3	KT-4
Kame Moraine	KM-1	KM-1	KM-3	KM-4
Glaciolacustine				
Beach	LB-1	LB-2	LB-3	LB-4
Delta	LD-1	LD-2	LD-3	LD-4
Marine				
Beach	MB-1	MB-2	MB-3	MB-4
Delta	MD-1	MD-2	MD-3	MD-4

Types of Deposits

GLACIOFLUVIAL SEDIMENTS

Outwash

Outwash deposits are sands and gravels deposited by glacial meltwaters beyond the glacier margins. They occur as sheet deposits or as terraced valley fills (valley trains) and may be very large in size. Well developed outwash deposits have predominantly horizontal bedding (Photo 2), are generally uniform in size-composition, and large clasts are rounded. Less well-developed outwash is more variable in terms of sizing. Proximal (near ice) units may have ice-contact features. The probability of locating useful granular aggregates is high to moderate depending on how much information on size grading and thickness is available. Several of the best gravel deposits in Ontario are located in this type of material e.g. the deposits of Caledon, Erin, Paris, Guelph, and the large undeveloped deposits of Grey County.

Ice-Contact Deposits

These include materials deposited by glacial meltwaters in contact with the glacier itself. Associated landforms are eskers, kames, end moraines (kame moraines), and ice-contact terraces (kame terraces). They are characterized by wide ranges of particle sizes (boulders to clay), extreme variability, deformation structures (Photo 3), till inclusions, variable crossbedding, and hummocky topography.

Ice-contact Terraces (kame terraces): These are glaciofluvial features deposited between the glacier and a confining topographic high such as the Niagara Escarpment. The deposits are similar to outwash except that they have extensive ice-contact features on the ice border side. They most commonly occur along the Niagara Escarpment and in re-entrants in the Escarpment such as the Hockley Valley. The probability of locating aggregates is high though the quality may be unpredictable. They are generally quite large in areal extent.

Eskers: These sinuous ridges usually parallel the local direction of glacier retreat and represent the deposits of meltwaters flowing in tunnels within or beneath the ice or in channels on the ice surface. They vary greatly in size and commonly

Photo 2—Well stratified outwash gravel, Paris Ontario.

Photo 3—Slump features in esker, Wingham Ontario.

consist of a gravel core flanked by sands. The probability of locating aggregates in these features is high though sand may predominate and much variability may be expected.

Virtually all eskers in southern Ontario have had pits in them at one time and many eskers have nearly been excavated in their entirety. On the other hand many of the large eskers have large remaining aggregate resources. Examples of eskers presently being worked are found at Frankford, Norwood, Omemee, Brampton, and Seaforth. The linear nature of eskers poses problems in planning as they cross numerous property lines; for example the Brampton esker has been worked in nine different locations over a 3-mile (5 km) length.

Kames: By definition these are isolated hills or knobs of ice-contact stratified drift. Classic examples are sparse in southern Ontario though features of similar origin are common. They form as small deltas, crevasse fillings, and depression fillings on or in contact with the glacier. On melting of the glacier they remain as collapsed features. They have a moderate probability of containing coarse aggregates. The deposit size and variability of material usually relegates these features to secondary sources and very few can maintain permanent processing equipment.

End Moraines: These are belts of glacial drift deposited at and parallel to the glacial margin. They frequently consist of ice-contact stratified drift and in such instances they are often referred to as kame moraines. The Oak Ridges, Orangeville, and Waterloo Moraines have been described as kame moraines though this is an oversimplification in places. Kame moraines frequently result from deposition between two glacial lobes (interlobate moraines).

These features pose a great problem to planners. They may be very large and contain vast aggregate resources, however the location of the aggregates is usually only poorly defined. How does a planner consider a large area for extractive zoning when the geologist tells him that only ten or twenty percent of the area is actually underlain by good aggregates? This remains a challenge for the geologist.

The probability of locating aggregates within such features is moderate to low. Exploration and development costs are high. The large number of pits and the variability of materials in Whitchurch and Uxbridge Townships are an example of the problem.

GLACIOLACUSTRINE DEPOSITS

These are the vestiges of former large lakes which formed when glaciers dammed up the natural drainage system. Several blockages of the St. Lawrence drainage system left numerous beach and deltaic features in southern Ontario. In northern Ontario glaciers retreating northward toward Hudson Bay upheld large lakes which normally would have drained northward.

Beach Deposits: Glacial lake shorelines are indicated by erosional bluffs or depositional features such as beaches and bars. The latter frequently

Photo 4—Well sorted beach gravels, Port Elgin Ontario.

contain useful aggregates. Well developed beach deposits are well stratified, are sorted into discrete size ranges (Photo 4), and pebbles and cobbles are well rounded and may be imbricated. Composition depends on the nature of the materials being reworked to form the beach and the size and time span of the attendant lake. The probability of locating coarse aggregates is high when the deposit is developed from a coarse substrate, such as stony till, and low when developed on fine grained materials. Beaches are linear, narrow features usually less than 20 feet (6 m) thick and frequently less than 10 feet (3 m) thick; large baymouth bars may be many times thicker than this.

Beach deposits of the well known Lake Iroquois have been worked in many places along the north shore of Lake Ontario. Many of these pits are now depleted and several have been reclaimed for use as parks, housing projects, or landfill sites.

Deltas: These formed when streams or rivers of glacial meltwaters debouched into lakes with subsequent deposition of transported sediments. In Ontario these deposits tend to consist mainly of sand and much silt. However in near ice or ice-contact situations coarse material may be present. The delta-beach complex of the so-called Fonthill Kame is an example of this. In other situations channel fills may provide coarse material or the upper beds (topsets) of the delta may essentially consist of outwash gravel; the deposits north of London are believed to be an example of the latter.

Although deltaic deposits may be very large, the probability of obtaining coarse material is generally low.

MARINE-GLACIOMARINE DEPOSITS

Surficial deposits of marine origin occur in eastern Ontario (Champlain Sea) and in the James Bay Lowland (Tyrrell Sea). These represent marine incursions while the land areas were recovering from the depression of the Earth's crust caused by the large mass of the recently withdrawn glaciers. Potential aggregate sources are similar to the lacustrine deposits.

Beaches: Beach deposits in eastern Ontario range from rock rubble, where beaches are weakly developed on thin bedded limestones, to well sorted gravels developed on coarse tills or older glaciofluvial materials. Fossil molluscs are present and clay beds may cause processing problems. Here too, beach deposits are linear and may pose planning problems; also many of these deposits are very small. The best beach deposits in eastern Ontario are reworked glaciofluvial materials as at Twin Elm, Herberts Corners, and Greely.

Deltas: Deltaic deposits laid down in the Champlain Sea consist mainly of fine sand. The deltas near Ottawa and Petawawa are examples. These materials are mainly useful for fill, sand cushion and other low value products.

EXTRACTIVE AREA RECOMMENDATION MAPS

If data are sufficient the geologist may interpret beyond the probability map shown in Figure 3 and make recommendations to the planners based on calculated "Possible"[1] aggregate reserves. These are determined from measured map area, a thickness estimate, and a tonnage factor of 2,500 tons per acre per foot of depth for sand and gravel. In areas underlain by suitable bedrock formations, this potential is calculated as well. Obvious cultural constraints are subtracted from the gross tonnage to give net tonnage for each deposit — this may only be a percentage factor in many cases. The various deposits are then ranked in terms of importance and recommendations are made to the municipality as to which deposits should be given priority for extractive zoning.

Figure 4 and Table 3 illustrate the data supplied for Brantford Township in southern Ontario (Cowan 1976) for six deposits considered to contain important aggregate resources. In this case an official of the Division of Mines, Ontario Ministry of Natural Resources, met with municipal officials and representatives from the aggregate industry to discuss the recommendations. Additional information from industry representatives allowed a size reduction of the areas and further reductions were made due to cultural and environmental conflicts. Through discussion accord was reached and the most important aggregate areas accepted for extractive zoning.

Summary

The above example provides a model for other groups to act upon, however it may only be accomplished when the basic data are available and are provided to the municipality in a suitable format.

[1]Performance Standards of the Association of Professional Engineers of the Province of Ontario.

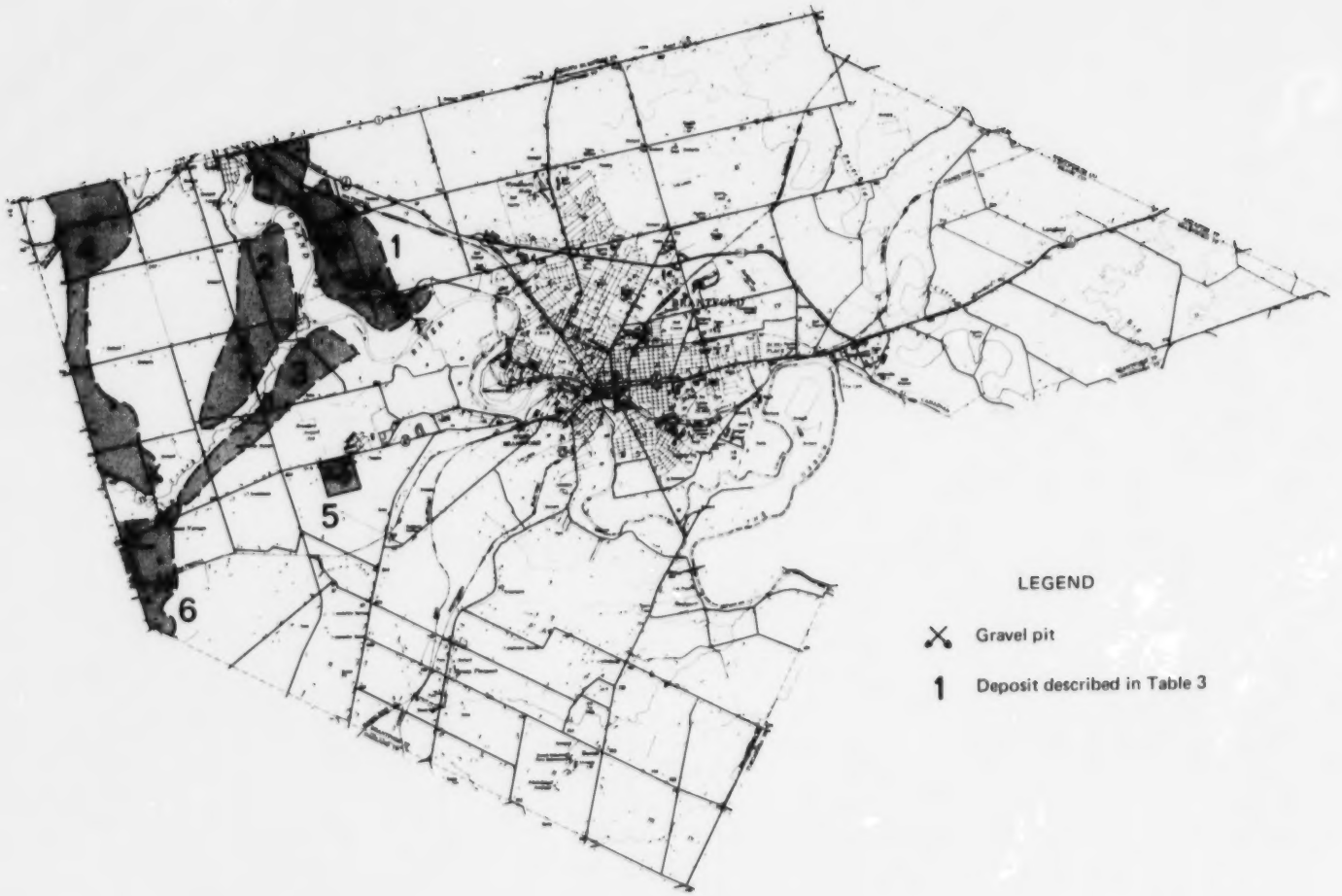

Figure 4–Brantford Township, showing areas recommended for extractive zoning.

TABLE 3 POSSIBLE AGGREGATE RESERVES FOR MAJOR DEPOSITS IN BRANTFORD TOWNSHIP (ABOUT 55 PERCENT OF POSSIBLE TOWNSHIP RESERVES). APPROXIMATELY 1400 ACRES WERE LICENSED IN 1975.

Area on Map	Approx. Acreage	Estimated Average Thickness (feet)	Gross Tonnage (Millions of Tons)	Estimated Cultural Loss %	Net Tonnage (Millions of Tons)
1	1000	30	75	10	67
2	1200	20	60	5	57
3	800	20	40	10	36
4	1750	25	109	10	98
5	175	20	8.8	5	8.3
6	650	30	48.8	15	41
TOTAL	5575				307

The Ontario Ministry of Natural Resources, through the Geological Branch, Division of Mines, has proposed to provide similar information to all townships now designated under The Pits and Quarries Control Act, 1971; it is expected that this will be expanded to include most of the heavily developed part of the Province within the near future.

The task of refining the rough data provided by the Ministry is monumental in some cases. In Brantford Township the aggregate industry was able to provide data which allowed streamlining. This is not going to be available in many areas and the municipalities must be prepared to accept the responsibility of either proving out aggregate resources or zoning extractive areas in which the resources are inadequately outlined.

THE FUTURE

The future of aggregate inventory in Ontario appears to be tripartite. Firstly much of central and northern Ontario has not been investigated though major targets have been outlined along the north shores of Lakes Huron and Superior (Gartner Lee Associates Limited 1974). Inventory of these areas will proceed as funding allows.

Secondly, in southern Ontario large areas of morainic deposits mapped as ice-contact stratified drift have to be re-investigated to define those areas actually underlain by economic aggregate resources. This will involve knowing the sedimentation history of the deposits and developing a co-ordinated geophysical and test drilling approach to measuring the resources. Until such an approach is refined we will be unable to provide the planners with adequate information. Similar methods will be required to explore buried aggregate resources. Given the techniques, who will pay for these costly procedures?

Finally, the investigation of geologic alternatives to the naturally washed sands and gravels we now use must be considered. What, for example, is the potential for producing aggregates from coarse-grained bouldery tills. This must be investigated; though processing costs would be higher these could be recovered by reducing transport costs. Alternate bedrock sources may exist; the physical properties of different facies of bedrock formations are not well known at present. The underground mining of bedrock aggregates is a topical solution to much of the problem, but to date no feasible proposals have come to light.

ADDITIONAL STUDIES

Auxiliary to the program carried out by the Phanerozoic Geology Section, the Division of Mines has commissioned several studies related to the regional planning exercise. Firstly, in 1973-74 a study was made of the Regional Municipality of Waterloo and South Wellington County by C.R. Bryant and A.G. McLellan of the University of Waterloo (Bryant and McLellan 1974). This study consisted of an aggregate inventory and inventory methodology, a computer study of a large gravel deposit, and recommendations for the effective planning of the areas underlain by aggregates.

From 1974 to 1976, the Ministry has had the Proctor and Redfern Group Limited analyse the aggregate needs, availability, and planning requirements and problems for the Central, Eastern, and Southwestern (administrative) Regions respectively. These served to outline the problems ahead if resource planning is not improved and also provided the public with a greater awareness of the problem.

CONCLUSIONS

Though the inventory of Ontario's mineral aggregate is incomplete we have provided or will provide in the immediate future inventory data for all municipalities designated under The Pits and Quarries Control Act, 1971. We plan to be able to do this for all southern Ontario and principal commercial centres of northern Ontario by 1980. In this regard we feel we have no North American peers. The immediate challenge is for all levels of government, environmentalists, planners, aggregate producers, and others to recognize that these are non-renewable resources, that they are finite, that there is presently no alternative, that they must be conserved, and that accord must be reached.

Future needs require that we determine the extent of poorly defined and buried aggregates and that we look for natural alternatives.

ACKNOWLEDGMENTS

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1976: Recommendations for Sand and Gravel Extractive Areas, Brantford Township; Ontario Div. Mines, OFR5200, 8p.

Gartner Lee Associates Ltd.
1974: Aggregate Resources Search — North Shore Lakes Superior and Huron, Districts of Thunder Bay and Algoma; Ontario Div. Mines, OFR5117, 116p.

Hackett, J.E. and McComas, M.R.
1969: Geology for Planning in McHenry County; Illinois State Geol. Surv., Circular 438, 29p.

Hewitt, D.F.
1960: The Limestone Industries of Ontario; Ontario Dept. Mines, IMC5, 177p.
1962: Urban Expansion and the Mineral Industries in the Toronto Hamilton Area; Ontario Dept. Mines, IMR8, 11p.
1968: Some Aspects of Environmental Geology; Ontario Dept. Mines, IMR26, 19p.

Hewitt, D.F. and Karrow P.F.
1963: Sand and Gravel in Southern Ontario; Ontario Dept. Mines, IMR11. 151p.

Hewitt, D.F. and Vos, M.A.
1970: Urbanization and Rehabilitation of Pits and Quarries; Ontario Dept. Mines, IMR34, 21p.

Hewitt, D.F. and Yundt, S.E.
1971: Mineral Resources of the Toronto-Centred Region; Ontario Dept. Mines and Northern Affairs, IMR38, 34p.

McLellan, A.G. and Bryant, C.R.
1975: The Methodology of Inventory — a Practical Technique for Assessing Provincial Aggregate Resources; CIM Bull., Vol. 68, No. 762, p.102-108.

Schwochow, S.D., Shroba, R.R., and Wicklein, P.C.
1974: Sand, Gravel, and Quarry Aggregate Resources, Colorado Front Range Counties; Colorado Geol. Surv., Special Publ. 5-A, 43p.

Vos, M.A.
1969: Stone Resources of the Niagara Escarpment; Ontario Dept. Mines, IMR3l, 68p.

APPENDIX A

PUBLISHED MAPS AND REPORTS: QUATERNARY GEOLOGY

ALEXANDRIA
Gwyn, Q.H.J. and Lohse, H.
1973: Quaternary Geology of the Alexandria Area, Southern Ontario; Ontario Div. Mines, Prelim. Map P.906, scale 1:50,000.

ALLISTON
Gwyn, Q.H.J. and White S.
1973: Quaternary Geology of the Alliston Area, Southern Ontario; Ontario Div. Mines, Prelim. Map P.835, scale 1:50,000.

BARRIE WEST
Burwasser, G.J., and Cairns, B.D.
1974: Quaternary Geology of the Barrie Area, (Western half), Southern Ontario; Ontario Div. Mines, Prelim Map P.978, scale 1:50,000.

BOLTON
White, O.L.
1975: Quaternary Geology of the Bolton Area, Southern Ontario; Ontario Div. Mines, GR117, 119p. Accompanied by Maps 2275 and 2276, scale 1 inch to 1 mile.

BRAMPTON
Hewitt, D.F.
1969: Industrial Mineral Resources of the Brampton Area; Ontario Dept. Mines, IMR23, 22p. Accompanied by Maps 2176 and 2179, scale 1 inch to 1 mile.

BRANTFORD
Cowan, W.R.
1972: Pleistocene Geology of the Brantford Area, Southern Ontario; Ontario Dept. Mines and Northern Affairs, IMR37, 66p. Accompanied by Maps 2240 and 2241, scale 1 inch to 1 mile.

BROCKVILLE — MALLORYTOWN
Henderson, E.P.
1970: Surficial Geology of Brockville and Mallorytown Map Areas, Ontario; Geol. Surv. Canada, Paper 70-18. Accompanied by Map 6-1970, scale 1:50,000.

CHALK RIVER
Gadd, N.R.
1963: Surficial Geology, Chalk River, Ontario-Quebec; Geol. Surv. Canada, Map 1132A, scale 1 inch to 1 mile.

COLLINGWOOD-NOTTAWASAGA
Burwasser, G.J.
1974: Quaternary Geology of the Collingwood-Nottawasaga Area, Southern Ontario; Ontario Div. Mines, Prelim. Map P.919. Scale 1:50,000.

CONESTOGO
Karrow, P.F.
1971: Quaternary Geology of the Stratford-Conestogo Area; Geol. Surv. Canada, Paper 70-34, 11p. Accompanied by Maps 26-1970, 27-1970, 28-1970 and 29-1970, scale 1:50,000.

CORNWALL
Terasmae, J.
1965: Surficial Geology of the Cornwall and St. Lawrence Seaway Project Areas, Ontario; Geol. Surv. Canada, Bull. 121, 54p. Accompanied by Map 1175A, scale 1 inch to 1 mile.

CORNWALL-CARDINAL
Owen, E.B.
1951: Pleistocene and Recent Deposits of the Cornwall-Cardinal Area, Stormont, Dundas, and Grenville Counties, Ontario; Geol. Surv. Canada, Paper 51-12, 25p. Accompanied by Map 51-12A, scale 1 inch to 1 mile.

DUNDALK
Gwyn, Q.H.J.
1972: Quaternary Geology of the Dundalk Area, Southern Ontario; Ontario Dept. Mines and Northern Affairs, Prelim. Map P.727. Scale 1:50,000.

DUNNVILLE
Feenstra, B.H.
1974: Quaternary Geology of the Dunnville Area, Southern Ontario; Ontario Div. Mines, Prelim. Map P.981. Scale 1:50,000.

ETOBICOKE
Watt, A.K.
1968: Pleistocene Geology and Ground Water Resources, Township of Etobicoke; Ontario Dept. Mines, GR59, 50p. Accompanied by Map 2111, scale 1 inch to ½ mile.

GANANOQUE — WOLFE ISLAND
Henderson, E.P.
1965: Surficial Geology, Gananoque-Wolfe Island; Geol. Surv. Canada, Map 13-1965. Scale 1 inch to 1 mile.

GRAND BEND
Cooper, A.J. and Clue, Jack
1974: Quaternary Geology of the Grand Bend Area, Southern Ontario; Ontario Div. Mines, Prelim. Map P.974. Scale 1:50,000.

GRIMSBY
Feenstra, B.H.
1975: Quaternary Geology of the Grimsby Area, Southern Ontario; Ontario Div. Mines, Prelim. Map P.993. Scale 1:50,000.

GUELPH
Karrow, P.F.
1968: Pleistocene Geology of the Guelph Area; Ontario Dept. Mines, GR61, 38p. Accompanied by Map 2153, scale 1 inch to 1 mile.

HAMILTON–GALT
Karrow, P.F.
1963: Pleistocene Geology of the Hamilton–Galt Area; Ontario Dept. Mines, GR16, 68p. (Out of Print). Accompanied by Maps 2029, 2030, 2033, 2034, scale 1 inch to 1 mile.

HAWKESBURY—LACHUTE
Gwyn, Q.H.J. and Thibault, J.J.L.
1975: Quaternary Geology of the Hawkesbury-Lachute Area, Southern Ontario; Ontario Div. Mines, Prelim. Map P.1010, scale 1:50,000.

KINGSTON
Henderson, E.P.
1973: Surficial Geology of Kingston (North Half) Map Area, Ontario; Geol. Surv. Canada, Paper 72-48, 6p. Accompanied by Maps 7-1972 and 8-1972, scale 1:125,000.

LAKE SIMCOE
Deane, R.E.
1950: Pleistocene Geology of Lake Simcoe District, Ontario; Geol. Surv. Canada, Mem. 256, 288p. Accompanied by Maps.

LINDSAY
Gravenor, C.P.
1955: Preliminary Map, Lindsay Area, Victoria, Ontario, Peterborough and Durham Counties; Geol. Surv. Canada, Paper 54-21. Scale 1 inch to 1 mile.

LINDSAY-PETERBOROUGH
Gravenor, C.P.
1957: Surficial Geology of the Lindsay-Peterborough Area; Geol. Surv. Canada, Mem. 288, 60p. Accompanied by maps.

LUCAN
Sado, E.V. and Vagners, U.J.
1975: Quaternary Geology of the Lucan Area, Southern Ontario; Ontario Div. Mines, Prelim. Map P.1048. Scale 1:50,000.

MARKHAM
Hewitt, D.F.
1969: Industrial Mineral Resources of the Markham-Newmarket Area; Ontario Div. Mines, IMR24, 41p. Accompanied by Map 2124, scale 1 inch to 1 mile.

MERRICKVILLE
Sharpe, D.R.
1975: Quaternary Geology of the Merrickville Area, Southern Ontario; Ontario Div. Mines, Prelim. Map P.991. Scale 1:50,000.

NEWMARKET
Gwyn, Q.H.J. and DiLabio, R.N.W.
1973: Quaternary Geology of the Newmarket Area, Southern Ontario; Ontario Div. Mines, Prelim. Map P.836. Scale 1:50,000.

NIAGARA
Feenstra, B.H.
1972: Quaternary Geology of the Niagara Area; Ontario Div. Mines, Prelim. Map P.764. Scale 1:50,000.

NORTH BAY—MATTAWA
Harrison, J.E.
1972: Quaternary Geology of the North Bay-Mattawa Region; Geol. Surv. Canada, Paper 71-26, 37p. Accompanied by Map 3-1971, scale 1:125,000.

NORTH YORK
Watt, A.K.
1955: Pleistocene and Ground-Water Resources of the Township of North York, York County; Ontario Dept. Mines, Vol. 64, pt.7, 64p. (published 1957). Accompanied by Map 1955-6, scale 1 inch to ½ mile.

ORANGEVILLE
Cowan, W.R.
1976: Quaternary Geology of the Orangeville Area, Southern Ontario; Ontario Div. Mines, GR141, 98p. Accompanied by Maps 2326, 2327, 2328, scale 1:50,000.

ORR LAKE—NOTTAWASAGA
Burwasser, G.J. and Boyd, S.T.
1974: Quaternary Geology of the Orr Lake (Western Half) — Nottawasaga (Eastern Half) Area, Southern Ontario; Ontario Div. Mines, Prelim. Map P.975. Scale 1:50,000.

OTTAWA
Gadd, N.R.
1963: Surficial Geology of Ottawa Map Area, Ontario and Quebec; Geol. Surv. Canada, Paper 62-16, 4p. Accompanied by Map 16-1962, scale 1 inch to 1 mile.

PALMERSTON
Cowan, W.R.
1976: Quaternary Geology of the Palmerston Area, Southern Ontario; Ontario Div. Mines, Prelim. Map P.1185. Scale 1:50,000.

PARKHILL
Cooper, A.J. and Clue, Jack
1976: Quaternary Geology of the Parkhill Area, Southern Ontario; Ontario Div. Mines, Prelim. Map P.1065. Scale 1:50,000.

PETERBOROUGH
Gravenor, C.P.
1952: Glacial Geology of the Peterborough Map Area, Ontario; Geol. Surv. Canada, Paper 52-14, 9p. Accompanied by Map, scale 1 inch to 1 mile.

RICE LAKE
Gravenor, C.P.
1953: Preliminary Map, Rice Lake Area, Northumberland, Durham and Peterborough Counties, Ontario; Geol. Surv. Canada, Paper 53-11, 2p.

Accompanied by Map 53-11, scale 1 inch to 1 mile.

SCARBOROUGH
Karrow, P.F.
1967: Pleistocene Geology of the Scarborough Area, Ontario Dept. Mines, GR46, 108p. Accompanied by Maps 2076 and 2077, scale 1 inch to ½ mile.

SCUGOG
Gravenor, C.P.
1953: Preliminary Map, Scugog Area, Durham, Ontario and Victoria Counties; Geol. Surv. Canada, Paper 53-26, 2p. Accompanied by Map 53-26, scale 1 inch to 1 mile.

SIMCOE
Barnett, P.J., Girard, C.K., and Watt, A.K.
1975: Quaternary Geology of the Simcoe Area, Southern Ontario; Ontario Div. Mines, Prelim. Map P.1054. Scale 1:50,000.

ST. MARYS
Karrow, P.F.
1977: Quaternary Geology of the St. Marys Area, Southern Ontario; Ontario Div. Mines, GR148, 59p. Accompanied by Map 2366, scale 1:50,000.

ST. THOMAS WEST
Dreimanis, A.
1964: Pleistocene Geology of the St. Thomas Area (West Half), Ontario Dept. Mines, Prelim. Map 238. Scale 1:50,000.

ST. THOMAS EAST
Dreimanis, A.
1970: Pleistocene Geology of the St. Thomas Area (East Half), Ontario Dept. Mines, Prelim. Map P.606. Scale 1:50,000.

STRATFORD – CONESTOGO
Karrow, P.F.
1971: Quaternary Geology of the Stratford-Conestogo Area, Ontario; Geol. Surv. Canada, Paper 70-34, 11p. Accompanied by Maps 26-170, 27-1970, 28-1970, and 29-1970, scale 1:50,000.

SUDBURY
Burwasser, G.J.
1972: Quaternary Geology and Industrial Mineral Resources of the Sudbury Area (Western Part) District of Sudbury; Ontario Div. Mines, Prelim. Map P.751. Scale 1:50,000.

SUDBURY
Burwasser, G.J.
1972: Quaternary Geology and Industrial Mineral Resources of the Sudbury Area (Eastern Part), District of Sudbury; Ontario Div. Mines, Prelim. Map P.752. Scale 1:50,000.

THORNHILL
Karrow, P.F.
1970: Pleistocene Geology of the Thornhill Area, Ontario Dept. Mines, IMR32, 51p. Accompanied by Map P.244, scale 1:25,000.

VAUDREUIL—HUNTINGDON
Gwyn, Q.H.J. and Girard, K.
1975: Quaternary Geology of the Vaudreuil-Huntingdon Area, Southern Ontario; Ontario Div. Mines, Prelim. Map P.1011. Scale 1:50,000.

WELLAND
Feenstra, B.H.
1972: Quaternary Geology of the Welland Area, Southern Ontario; Ontario Div. Mines, Prelim. Map P.796. Scale 1:50,000.

WESTPORT
Henderson, E.P.
1967: Surficial Geology, Westport, Ontario; Geol. Surv. Canada, Map 22-1966. Scale 1 inch to 1 mile.

WINDSOR—ESSEX EAST
Vagners, U.J.
1972: Quaternary Geology of the Windsor-Essex Area (Eastern Part), Southern Ontario; Ontario Dept. Mines and Northern Affairs, Prelim. Map P.750. Scale 1:50,000.

WINDSOR—ESSEX WEST
Vagners, U.J.
1972: Quaternary Geology of the Windsor-Essex Area (Western Part) Southern Ontario; Ontario Dept. Mines and Northern Affairs, Prelim. Map P.749. Scale 1:50,000.

WOODSTOCK
Cowan, W.R.
1974: Quaternary Geology of the Woodstock Area, Southern Ontario; Ontario Div. Mines, GR119, 91p. Accompanied by Maps 2281 and 2282, scale 1 inch to 1 mile.

APPENDIX B

PUBLISHED REPORTS: RECOMMENDATIONS FOR SAND AND GRAVEL EXTRACTIVE AREAS

ADJALA

OFR 5199 Recommendations for Sand and Gravel Extractive Areas, Adjala Township, Simcoe Country, Southern Ontario (30 M/13W, 31D/-4W); by Q.H.J. Gwyn, approximately 8p., 2 tables, 3 maps.

BRANTFORD

OFR 5200 Recommendations for Sand and Gravel Extractive Areas, Brantford Township, Brant County, Southern Ontario (40 P/1); by W.R. Cowan, approximately 8p., 2 tables, 2 maps.

BRIGHTON

OFR 5201 Recommendations for Sand and Gravel Extractive Areas, Brighton Township, Northumberland County, (31 C/4); by John Z. Fraser, approximately 9p, 2 tables, 1 map.

BROCK

OFR 5164 Recommendations for Sand and Gravel Extractive Areas, Brock Township, Southern Ontario (31 D/6, 7; 30 M/2,3); by Q.H.J. Gwyn, 10p., 2 tables, 3 maps.

CALEDON

OFR 5202 Recommendations for Sand and Gravel Extractive Areas, Caledon Township, Peel County, Southern Ontario (30 M/12W, 13W; 40 P/-16E); by John Z. Frazer, approximately 11p., 2 tables, 2 maps.

CRAMAHE

OFR 5203 Recommendations for Sand and Gravel Extractive Areas, Cramahe Township, Northumberland County, Southern Ontario (30 N/-13W; 31 C/4W); by John Z. Fraser, approximately 8p., 2 tables, 2 maps.

ERAMOSA

OFR 5188 Recommendations for Sand and Gravel Extractive Areas, Eramosa Township, Southern Ontario (40 P/9); by G.J. Burwasser, approximately 14p, 2 tables, 3 maps.

ERIN

OFR 5189 Recommendations for Sand and Gravel Extractive Areas, Erin Township, Southern Ontario (30 M/12W; 40 P/9E, 16E); by W.R. Cowan, approximately 10p., 2 tables, 4 maps.

GUELPH CITY

OFR 5190 Recommendations for Sand and Gravel Extractive Areas, Municipality of Guelph (Guelph City), Southern Ontario (40 P/9E); by G.J. Burwasser, approximately 12p., 1 table, 2 maps.

GUELPH TOWNSHIP

OFR 5191 Recommendations for Sand and Gravel Extractive Areas, Guelph Township, Southern Ontario (40 P/8, 9), by G.J. Burwasser, approximately 12p., 2 tables,3 maps.

MANVERS

OFR 5204 Recommendations for Sand and Gravel Extractive Areas, Manvers Township, Durham County, Southern Ontario (31 D/2E, 7E); by Q.H.J. Gwyn, 11p., 2 tables, 2 maps.

MONO

OFR 5205 Recommendations for Sand and Gravel Extractive Areas, Mono Township, Dufferin County, Southern Ontario (30 M/13W; 31 D/-4W; 40 P/16E; 41 A/E); by W.R. Cowan and Q.H.J. Gwyn, llp., 2 tables 4 maps.

MULMER

OFR 5206 Recommendations for Sand and Gravel Extractive Areas, Mulner Township, Dufferin County, Southern Ontario (31D/4W; 41 A/1E, 8E); by Q.H.J. Gwyn, 10p., 2 tables, 3 maps.

NORTH DUMFRIES

OFR 5207 Recommendations for Sand and Gravel Extractive Areas, North Dumfries Township, Waterloo County, Southern Ontario (40 P/8); by W.R. Cowan, 11p., 2 tables, 2 maps.

PILKINGTON

OFR 5192 Recommendations for Sand and Gravel Extractive Areas, Pilkington Township; Southern Ontario, (40 P/9W; 10E); by G.J. Burwasser, approximately 11p., 2 tables, 2 maps.

PUSLINCH

OFR 5193 Recommendations for Sand and Gravel Extractive Areas, Puslinch Township, Southern Ontario (40 P/8, 9); by G.J. Burwasser, approximately 13p., 2 tables 3 maps.

SOUTH DUMFRIES

OFR 5208 Recommendations for Sand and Gravel Extractive Areas, South Dumfries Township, Brant County, Southern Ontario (40 P/1,8); by W.R. Cowan, 11p., 2 tables, 4 maps.

WHITCHURCH

OFR 5178 Recommendations for Sand and Gravel Extractive Areas, Whitchurch Township, Southern Ontario, (30 M/14; 31 D/3)); by Q.H.J. Gwyn, 8p., 2 tables, 3 maps.